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1.	Your reference	BP-09-0361
	18 JUL 2003	
2.	Patent application number *(The Patent Office will fill in this part)*	0316946.3 21JUL03 E823923-4 D02826 P01/7700 0.00-0316946.3
3.	Full name, address and postcode of the or of each applicant *(underline all surnames)* 06832232001 Patents ADP number *(if you know it)* If the applicant is a corporate body, give the country/state of its incorporation	THE MORGAN CRUCIBLE COMPANY PLC Morgan House Madeira Walk Windsor Berkshire SL4 1EP United Kingdom
4.	Title of the invention	FLOW FIELD PLATE GEOMETRIES
5.	Name of your agent *(if you have one)* "Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)* Patents ADP number *(if you know it)*	Phillips & Leigh 5 Pemberton Row London EC4A 3BA United Kingdom 00001289001

		Country	Priority application number *(if you know it)*	Date of filing *(day / month / year)*
6.	If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these earlier applications and *(if you know it)* the or each application number	International	PCT/GB03/002621	18th June 2003

		Number of earlier application	Date of filing *(day / month / year)*
7.	If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application		

8.	Is a statement of inventorship and of right to grant of a patent required in support of this request? *(Answer 'Yes' if:* *a) any applicant named in part 3 is not an inventor, or* *b) there is an inventor who is not named as an applicant, or* *c) any named applicant is a corporate body.* *See note (d))*	Yes

9. Enter the number of sheets for any of the following items you are filing with this form. Do not count copies of the same document

Continuation sheets of this form	
Description	11
Claim(s)	1
Abstract	1
Drawing(s)	11 + 11 RM.

10. If you are also filing any of the following, state how many against each item.

Priority documents	
Translation of priority documents	
Statement of inventorship and right to grant of a patent *(Patents Form 7/77)*	
Request for preliminary examination and search *(Patents Form 9/77)*	1
Request for substantive examination *(Patents Form 10/77)*	1
Any other documents *(please specify)*	

11. I/We request the grant of a patent on the basis of this application.

Signature Date

18th July 2003

12. Name and daytime telephone number of person to contact in the United Kingdom

J.C. Boff
020 7822 8888

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DUPLICATE

FLOW FIELD PLATE GEOMETRIES

This invention relates to fuel cells and electrolysers, and is particularly, although not exclusively, applicable to proton exchange membrane fuel cells and electrolysers.

Fuel cells are devices in which a fuel and an oxidant combine in a controlled manner to produce electricity directly. By directly producing electricity without intermediate combustion and generation steps, the electrical efficiency of a fuel cell is higher than using the fuel in a traditional generator. This much is widely known. A fuel cell sounds simple and desirable but many man-years of work have been expended in recent years attempting to produce practical fuel cell systems. An electrolyser is effectively a fuel cell in reverse, in which electricity is used to split water into hydrogen and oxygen.

Both fuel cells and electrolysers are likely to become important parts of the so-called "hydrogen economy". In the following, reference is made to fuel cells, but it should be remembered that the same principles apply to electrolysers. One type of fuel cell in commercial production is the so-called proton exchange membrane (PEM) fuel cell [sometimes called polymer electrolyte or solid polymer fuel cells (PEFCs)]. Such cells use hydrogen as a fuel and comprise an electrically insulating (but ionically conducting) polymer membrane having porous electrodes disposed on both faces. The membrane is typically a fluorosulphonate polymer and the electrodes typically comprise a noble metal catalyst dispersed on a carbonaceous powder substrate. This assembly of electrodes and membrane is often referred to as the membrane electrode assembly (MEA).

Hydrogen fuel is supplied to one electrode (the anode) where it is oxidised to release electrons to the anode and hydrogen ions to the electrolyte. Oxidant (typically air or oxygen) is supplied to the other electrode (the cathode) where electrons from the cathode combine with the oxygen and the hydrogen ions to produce water. A sub-class of proton exchange membrane fuel cell is the direct methanol fuel cell in which methanol is supplied as the fuel. This invention is intended to cover such fuel cells and indeed any other fuel cell.

In commercial PEM fuel cells many such membranes are stacked together separated by flow field plates (also referred to as bipolar plates or separators). The flow field plates are typically formed of metal or graphite to permit good transfer of electrons between the anode of one membrane and the cathode of the adjacent membrane. The flow field plates have a pattern of grooves on their surface to supply fluid (fuel or oxidant) and to remove water produced as a reaction product of the fuel cell.

Various methods of producing the grooves have been described, for example it has been proposed to form such grooves by machining, embossing or moulding (WO00/41260), and (as is particularly useful for the present invention) by sandblasting through a resist (WO01/04982). International Patent Application No. WO01/04982 disclosed a method of machining flow field plates by means of applying a resist or mask to a plate and then using sandblasting (or other etching method using the momentum of moving particles to abrade the surface, e.g. waterjet machining), to form features corresponding to a pattern formed in the mask or resist.

Such a process was shown by WO01/04982 as capable of forming either holes through the flow field plates, or closed bottom pits or channels in the flow field plates. The process of WO01/04982 is incorporated herein in its entirety, as giving sufficient background to enable the invention.

In practice, the majority of plates made to date have been formed by milling the channels.

WO00/41260 discloses a flow field geometry in which substantially straight parallel channels are provided of a width less than about 0.75mm.

WO00/26981 discloses a similar geometry in which highly parallel flow channels of a width less than 800μm separated by lands of less than 800μm are used and in which the inter-channel land area is less than 25% of the flow field. Preferred land widths are narrower still. This geometry is stated to improve gas distribution as reducing the need for lateral gas dispersion through the MEA (referred to in WO00/26981 as the DCC [diffusion current collectors]). The geometry is also stated to reduce electrical resistance as it reduces the electrical path length to land areas.

There is a conflict between electrical and gas properties described in WO00/26981, in that reduced land areas are stated to increase electrical resistance. WO00/26981 states that these conflicting requirements may be optimised. WO00/26981 states that the pattern of highly parallel micro-channels may contain interconnections or branch points such as in hatchings or grid patterns. One advantage of the use of narrow channels is stated to be that this encourages water droplet formation across the channels so permitting efficient water removal. However this advantage may not be seen where a grid pattern is used as the pressure either side of a water droplet is likely to be substantially equal.

Cited against WO00/26981 are:-

- US 3814631, which discloses an electrode construction in which micro-channels of more than 0.3mm wide are provided in a frame edge leading to a textured electrode in which protrusions on one face of the electrode match depressions in the opposed face of the electrode.
- US 5108849, which discloses a plate having serpentine tracks of 0.76mm (0.03 inch) width or more with land widths of 0.254mm (0.01 inch) or more.
- WO94/11912, which discloses a plate having discontinuous tracks of 0.76mm (0.03 inch) width and depth. These tracks may be interdigitated.
- WO98/52242, which discloses means for humidifying the membrane,

Narrow channels are known for other devices, for example, WO94/21372 discloses a chemical processing apparatus comprising a three dimensional tortuous channel formed by aligning part channels in adjacent discs. Such a construction has not been used for a fuel cell.

None of the fuel cell related patents disclose a structure of relatively coarse gas delivery channels leading to fine gas channels.

To ensure that the fluids are dispersed evenly to their respective electrode surfaces a so-called gas diffusion layer (GDL) is placed between the electrode and the flow field plate. The gas diffusion layer is a porous material and typically comprises a carbon paper or cloth, often having a bonded layer of carbon powder on one face and coated with a hydrophobic material to promote water rejection. It has been proposed to provide an interdigitated flow field below a macroporous material (US-A-5641586) having connected porosity of pore size range 20-100μm allowing a reduction in size of the gas diffusion layer. Such an arrangement permits gas flow around blocked pores, which is disadvantageous. Build up of reactant products (such as water) can occur in these pores reducing gas transport efficiency. Additionally, such a structure increases the thickness of the flow field plate.

An assembled body of flow field plates and membranes with associated fuel and oxidant supply manifolds is often referred to a fuel cell stack.

Although the technology described above has proved useful in prototype and in some limited commercial applications, to achieve wider commercial acceptance there is now a demand to reduce the physical size of a fuel cell stack and to reduce its cost. Accordingly, a reduction in the number of components could have beneficial results on size and cost (both through material and assembly costs).

Also, the prior art flow field plates have provided flow fields of matrix, serpentine, linear, or interdigitated form but have not looked to other physical systems for improving the gas flow pathways. Matrix flow fields (in which a grid of lands is provided to support the gas diffusion layer and gas flows between the lands) theoretically provide good gas flow but in practice have had the disadvantage that water is readily trapped within the matrix and blocks it. Further, any blockage can lead to stagnant areas in the flow field.

Linear and serpentine flow fields have fewer problems with water blockage or stagnant areas but have a lower gas flow for a given pressure drop across the flow field. Serpentine flow field patterns also tend to have a problem with gas "short circuiting" by passing from one channel to an adjacent channel having a significantly lower pressure.

Interdigitated flow fields provide a highly efficient delivery of gas but have the disadvantage that high pressures are required to force the gas from the incoming flow field, through the gas diffusion layer, to the outgoing flow field and this results in high parasitic losses.

Additionally, the applicant has modelled the behaviour of conventional flow field plate designs and found that under conditions of high demand (e.g. currents of 0.6A/cm^2 or higher) such conventional plates are liable to depletion of oxidant and/or fuel over large parts of the flow field plate.

Known requirements of gas flow fields are:-

- sufficient land area to support the GDL and maintain a cavity for flow of gas
- sufficiently narrow channels to prevent the GDL squeezing into and blocking the channels under the compressive pressures holding the stack together
- and, from WO00/26981, sufficiently narrow channels to reduce the path length of current from areas over the channel to lands, and sufficiently narrow lands to reduce the diffusion distance of gas to areas over the lands.

What WO00/26981 does not solve, except by partition of flow field plates into separate areas, is that narrow channels imply a high pressure drop and so a distinct difference in gas availability from one end of the channels to the other.

In a conventional flow field plate design, the pressure at one end (the inlet end) of the flow field is significantly lower than at the other end (the outlet end) as reactant gases are both consumed in operation of the fuel cell and because of the resistance to flow of the gases. As the demand for fuel or oxidant increases, the ability of such arrangements to deliver reactant gas effectively towards the reactant gas outlet diminishes. The applicant has realised that what is required is a means to provide efficient gas delivery to the whole of the working surface of the fuel cell (that area where effective electrical generation takes place), and in particular in the region of the flow field outlet, so that starvation of reactants does not occur.

The applicant has realised that by looking to physiological systems (the lung) improved flow field geometries may be realised that are likely to have lower parasitic losses due to their shorter gas flow pathways and to have better distribution of reactants over the flow field.

In WO02/065566 the applicants claimed a flow field plate having an assembly of progressively narrowing pattern of channels which could link or be interdigitated with an opposed similar assembly of channels.

In co-pending PCT/GB2003/002621 the applicants have disclosed flow fields comprising geometries in which gas is delivered by gas delivery channels to a permeable wall, and is then transferred through the permeable wall to gas removal channels. Improved evenness of gas distribution was shown, but this application did not concern itself with water management issues.

The applicants have conducted further trials and found that the geometries of PCT/GB2003/002621 can be improved by a different arrangement of gas delivery and gas removal channels, and that matrix flow fields can be improved in like manner.

Accordingly, the present invention provides a flow field plate (separator) for a fuel cell or electrolyser, comprising one or more branched primary gas delivery/removal channels feeding narrower secondary gas diffusion channels defined by an array of lands forming a network of interconnected gas diffusion channels therebetween.

The branched gas delivery channels may simply feed the gas diffusion channels, which themselves lead directly or via a gas removal channel to a gas outlet.

Preferably the flow field plate comprises one or more branched gas delivery channels, interdigitated with one or more branched gas removal channels, and a permeable wall separating same formed by the array of lands.

Further features of the invention are set out in the claims and as exemplified by the following description with reference to the drawings in which:-

Fig. 1	shows in plan a flow field plate design in accordance with the invention of PCT/GB2003/002621;
Fig. 2	shows an enlarged plan view of area A of Fig. 1;
Fig. 3	shows an alternative a flow field plate design in accordance with both the invention of PCT/GB2003/002621 and the present invention;
Fig. 4	shows an enlarged plan view of area E of Fig. 3;
Fig. 5	shows in part a design for an array type flow field comprising a hexagonal array of channels in accordance with the present invention;

Fig. 6 shows a further design in accordance with the invention of PCT/GB2003/002621;

Fig. 7 shows a design in accordance with the present invention;

Fig. 8 shows polarisation curves of some flow field designs;

Fig. 9 shows power curves for some designs;

Fig. 10 shows graphically the improvement in power output measured for a design according to the present invention and a conventional design; and

Fig. 11 is an alternative channel arrangement for use in the design of Fig.5.

Figs. 1 and 2 show a flow field plate in accordance with the invention of PCT/GB2003/002621. A flow field plate 1 comprises manifolds and fastening holes 2 in a peripheral frame 18 that forms no part of the actual flow field. The plate also comprises a gas supply channel 3 to which a reactant gas is delivered by a manifold (not shown). Channel 3 communicates with gas delivery channels 4. Gas delivery channels 4 themselves connect to gas delivery sub-channels 5. In similar manner, a gas drain channel 6 connects with gas removal channels 7 and gas removal sub-channels 8.

The gas delivery channels and sub channels 4,5 and the gas removal channels and sub-channels 7,8 define between them a wall 9 having a plurality of diffusion channels 10 that offer a flow path from the gas delivery channels and sub channels 4,5 to the gas removal channels and sub-channels 7,8. In a typical case, for a small fuel cell having a plate size of ~10cm×10cm and a flow field working surface of ~6.5cm×6.5cm, the width of the gas delivery channels would be about 1.25mm, for the sub-channels about 0.5mm, and for the diffusion channels about 0.125mm.

The wall is convoluted on two scales.

On a first scale, it extends in a pleated or concertinaed manner from the gas supply channel 3 to the gas drain channel 6 and comprises wall segments 16 along each fold of the wall, and end wall segments 17 at each turn of the wall. The length of each fold of the wall is about 6cm in the example shown.

On a second scale, the walls between end wall segments 17 are themselves pleated or concertinaed to form the gas delivery and gas removal sub channels 5,8. The length of the gas delivery and gas removal sub-channels is about 2.5mm in the example shown.

This pattern can be repeated on a smaller or larger scale still.

This fractal type arrangement of the flow field, in which gas passes through progressively diminishing channels, means that the arrangement is to some extent scalable to the size of the flow field plate. It further ensures a large surface area to the permeable wall.

This arrangement also ensures that the GDL is well supported by the flow field while ensuring that parts of the MEA lying above the land areas of the flow field are only a short distance from a channel (typically, for the arrangement shown, for the wall segments 16, within 0.5 mm or less of the closest channel and for end wall segment 17, within 1.25mm or less). This arrangement is readily scalable such that smaller wall segments 16 may be used giving still better access of gas to the area above the lands. Preferably no part of the flow field (and in particular of the wall segment 16) is more than 0.25mm from the closest gas delivery or diffusion channel.

To form both gas delivery and gas diffusion channels a technique such as sand blasting may be used in which a patterned template or resist is placed against the surface of a plate, the template or resist having a pattern corresponding to the desired channel geometry. Such a technique is described in WO01/04982, which is incorporated herein in its entirety as enabling the present invention. With this technique the plates may be formed from a graphite/resin composite or other non-porous electrically conductive material that does not react significantly with the reactants used.

Alternatively, the wall could be deposited onto a plate (e.g. by screen printing or the like) and in this case could be formed of a gas permeable material without the use of gas diffusion channels. It will be readily apparent to the person skilled in the art that there are many ways of producing a permeable wall.

Such methods can be used to make all of the flow fields described herein.

Figs. 3 and 4 show an alternative flow field plate design in accordance with the principles of the present invention. A flow field plate comprises a central area 19 (for use with a surrounding frame 18 [not shown] as in Fig. 1). This has a gas supply channel 3 and a gas drain channel 6 and end wall segments 17 as in Fig. 1. The permeable walls are defined by an array of lands 20 forming a network of fine gas diffusion channels therebetween. Although circular lands are shown, the applicant has found that hexagonal or other lands offering a relatively constant channel width therebetween (e.g. polygonal lands) are preferred. A typical size for the lands is ~750μm ± 250μm with a spacing between lands of ~300μm ± 150μm.

Fig 5 shows in part a design for an array type flow field comprising a hexagonal array of channels connecting inlet channel 29 to outlet channel 30. The array comprises primary gas delivery/removal channels 31 defining a series of blocks 32 each themselves comprising a plurality of interconnected gas diffusion channels. In Fig. 5 the gas diffusion channels themselves form a hexagonal array, but Fig. 11 shows that other arrays of interconnected gas diffusion channels are feasible and contemplated. As with Figs. 3 and 4, although circular lands may be used, the applicant has found that hexagonal or other lands offering a relatively constant channel width therebetween are preferred. Again, a typical size for the lands is ~750μm ± 250μm with a spacing between lands of ~300μm ± 150μm.

Fig. 6 shows in a similar view a further design in accordance with the invention of PCT/GB2003/002621 in which the permeable wall comprises a series of gas diffusion channels extending at an angle to the gas delivery channels. Typical widths for the gas diffusion channels are ~400μm ± 250μm.

Fig. 7 shows in more detail a design in accordance with the present invention, in which an inlet channel 21 connects to a branched gas delivery channel comprising a main stem 22 with branches 23. The branches 23 are interdigitated with branches 24 from the stems 25 of two branched gas removal channels feeding into an outlet channel 26. A permeable wall defined by lands separates the branched gas delivery channel from the branched gas removal channels.

Subsidiary channels 27 and 28 extend from the inlet channel 21and outlet channels 26 respectively to provide additional gas delivery/removal to regions where the branched gas delivery/removal channels do not extend.

The performance of various flow field geometries were compared as air-side geometries (where water management problems would be revealed) and their relative performance is shown in Figs. 8 and 9, in which Fig. 8 is a polarisation curve comparison of various designs, and Fig. 9 is a corresponding power curve.

The apparatus used to obtain this data comprised Hydrogenics Corporation Screener test stands using Nafion membranes and Toray gas diffusion media. The apparatus was run with Hydrogen at 80% humidity anode and with air also at 80% humidity. All test were isothermal at 80°C on single cells. The same geometry was used on the anode at 90° to the air flow direction.

The geometries examined were as set out in Table 1. All of the flow field plates were generally square in form of size 100mm × 100mm and with an active area of size 70mm × 70mm.

It will be seen from the graphs that the Col design has by far the worst performance of the designs tested. The applicants ascertained that this was due to water being trapped in the interstices of the array due to the varying cross section of the gas diffusion channels (an array of round dots leads to channels that bulge and shrink along their length as seen in Fig. 4). To reduce the risk of such water trapping, the applicants produced the Hex array and a dramatic improvement can be seen.

Similarly, the Bio Orig design showed poor performance compared with a serpentine design due to water management problems (even though giving good gas distribution). The Bio 1000 design was an attempt to improve this, but again, the use of round columns lead to problems with water trapping.

The Bio 2000 design was an attempt to reduce the opportunity for water to get trapped, by providing gas diffusion channels of substantially uniform cross-section. It can be seen that this design gives an improved performance, compared to the conventional Serp design, at high-voltage/low-current-density conditions and at low-voltage/high-current-density conditions but is poorer in the mid range.

The Leaf design is comparable with the Serp design at low to medium voltage/current conditions, but when the cell is heavily loaded at high current density the Leaf design gives significantly more power (>10% more when operating over 1.5 $A.cm^{-2}$). The applicants confidently expect that the Leaf design, using hexagonal lands, will exceed this performance.

Table 1	
Plate Identifier	Description
Serp	A serpentine design having 5 tracks of width 750μm and depth 750μm
Col	A matrix design comprising an array of round columns of diameter ~750μm with a spacing between lands of ~300μm.
Hex	A design in accordance with Fig. 5, and having a primary channel 31 of width 750μm and in which the lands were formed as hexagonal columns of width ~750μm with a spacing between lands of ~300μm.
Bio Orig	A design according to Figs. 1 and 2 with gas delivery channel 4 of width about ~1250μm, sub-channels 5 of width about ~750μm, and diffusion channels 10 about 125μm.
Bio 1000	A design according to Figs. 3 and 4 with gas delivery channel of width 1000μm and having a permeable wall defined by an array of lands formed as round columns of diameter ~750μm with a spacing between lands of ~300μm.
Bio 2000	A design according to Fig. 6 having a gas delivery sub-channels of width 1000μm and gas diffusion channels of width ~400μm.
Leaf	A design according to Fig. 7 with a main stem 22 of width 2mm at its base, with branches 23 of width 1mm, having a permeable wall defined by an array of lands formed as round columns of width ~750μm with a spacing between lands of ~300μm.

Fuel cells are usually managed so as to operate at their optimum voltage/current density regime, which for serpentine channels generally means below 0.6-0.8A.cm^{-2}. The Leaf design makes it possible to operate at higher current densities (e.g. 1.6A.cm^{-2}) while giving high power (power densities in excess of 750mW.cm^{-2} or even > 800 mW.cm^{-2} calculated on the working surface of the flow field are achievable). Even without optimising the fuel cell management system to suit this flow field geometry, such high load performance is particularly important for applications where high intermittent loads are experienced.

To assist pressure equalisation along the channels, they may taper, as is described in International Patent Application No. WO02/065565.

CLAIMS

1. A flow field plate (separator) for a fuel cell or electrolyser, comprising one or more branched primary gas delivery/removal channels feeding narrower secondary gas diffusion channels defined by an array of lands forming a network of interconnected gas diffusion channels therebetween.

2. A flow field plate, as claimed in Claim 1, in which the branched primary gas delivery/removal channels comprise a hexagonal network of channels.

3. A flow field plate, as claimed in Claim 1, comprising one or more branched gas delivery channels, interdigitated with one or more branched gas removal channels, and a permeable wall separating same formed by the array of lands.

4. A flow field plate as claimed in Claim 3, in which the permeable wall is concertinaed, having wall segments extending along each fold of the wall, and end wall segments at each turn of the wall.

5. A flow field plate, as claimed in any one of Claims 1 to 4, in which the lands are shaped to define gas diffusion channels having substantially constant width.

6. A flow field plate, as claimed in Claim 5, in which the lands are polygonal in form.

7. A flow field plate, as claimed in Claim 6, in which the lands are hexagonal in form

8. A flow field plate, as claimed in any one of Claims 1 to 4, in which the lands are shaped to define gas diffusion channels tapering such that in use surface tension effects tend to drive water out of the channels.

9. A fuel cell comprising one or more flow field plates in accordance with any one of Claims 1 to 8.

10. A fuel cell as claimed in Claim 9, in which the power deliverable by each flow field plate is in excess of $750mW.cm^{-2}$ calculated on the working surface of the flow field.

11. A fuel cell as claimed in Claim 10, in which the power deliverable by each flow field plate is in excess of $800mW.cm^{-2}$.

Agent's Ref: BP-09-0361

ABSTRACT

A flow field plate comprises one or more branched primary gas delivery/removal channels feeding narrower secondary gas diffusion channels defined by an array of lands forming a network of interconnected gas diffusion channels therebetween.

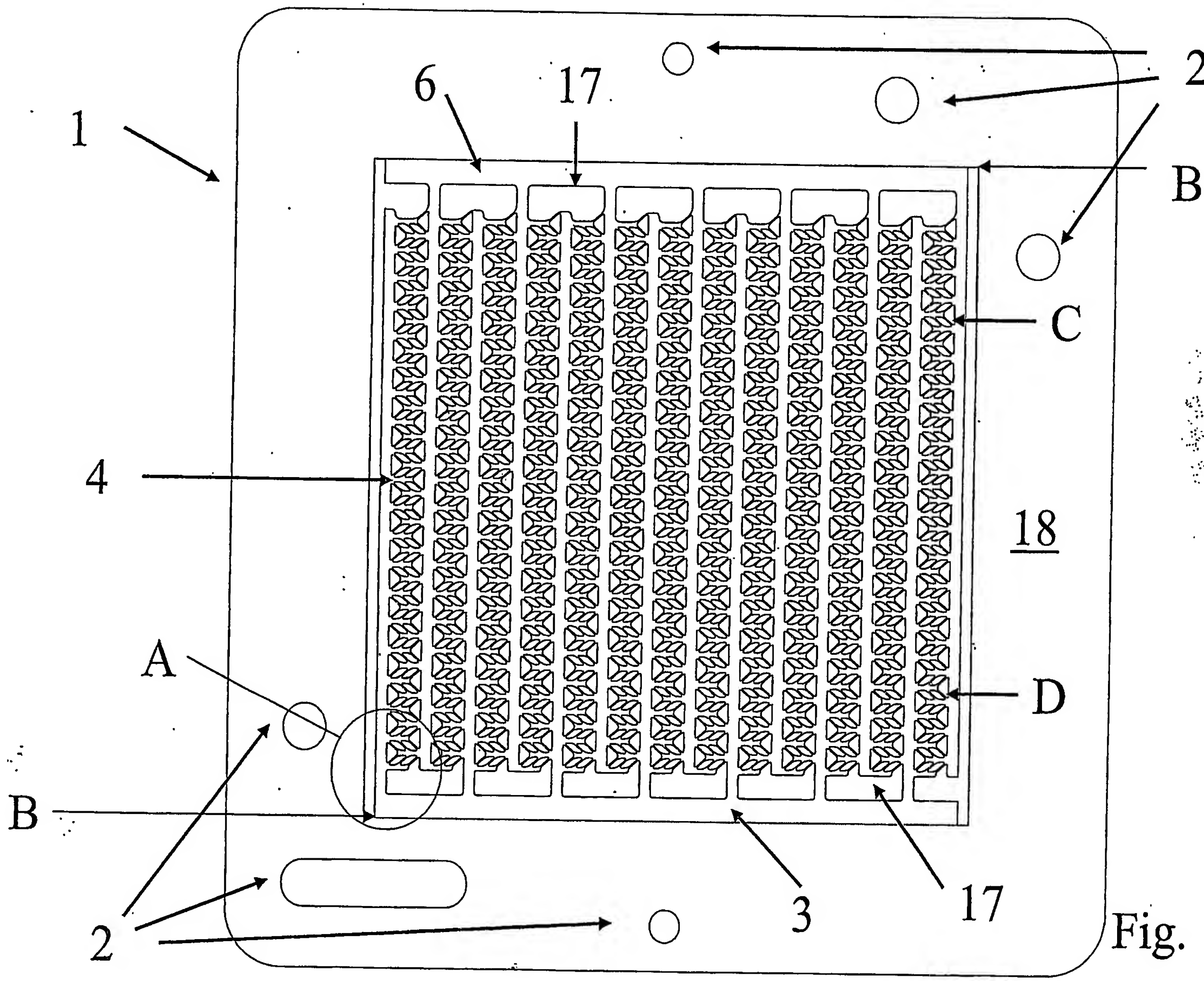


Fig. 1

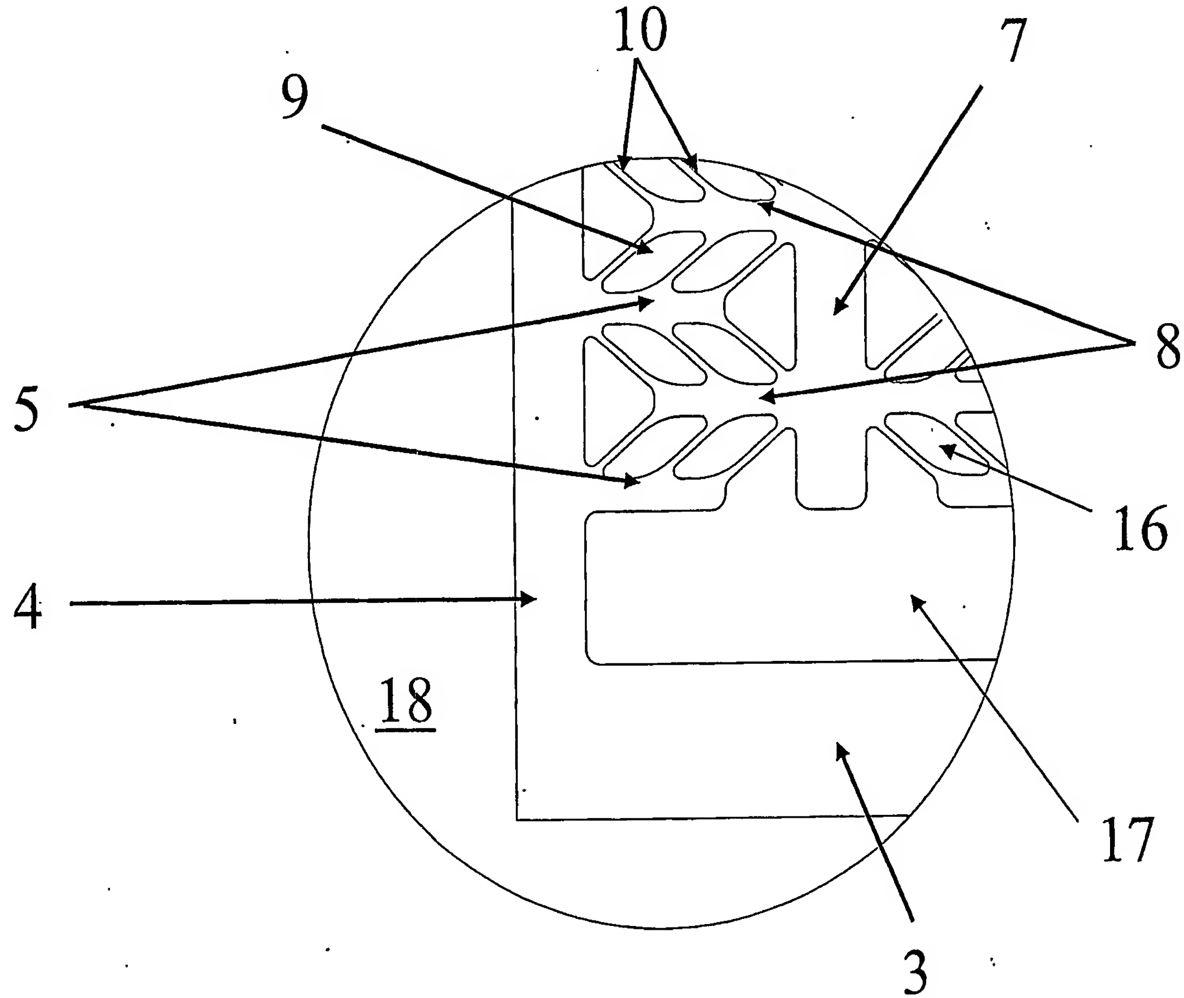


Fig. 2

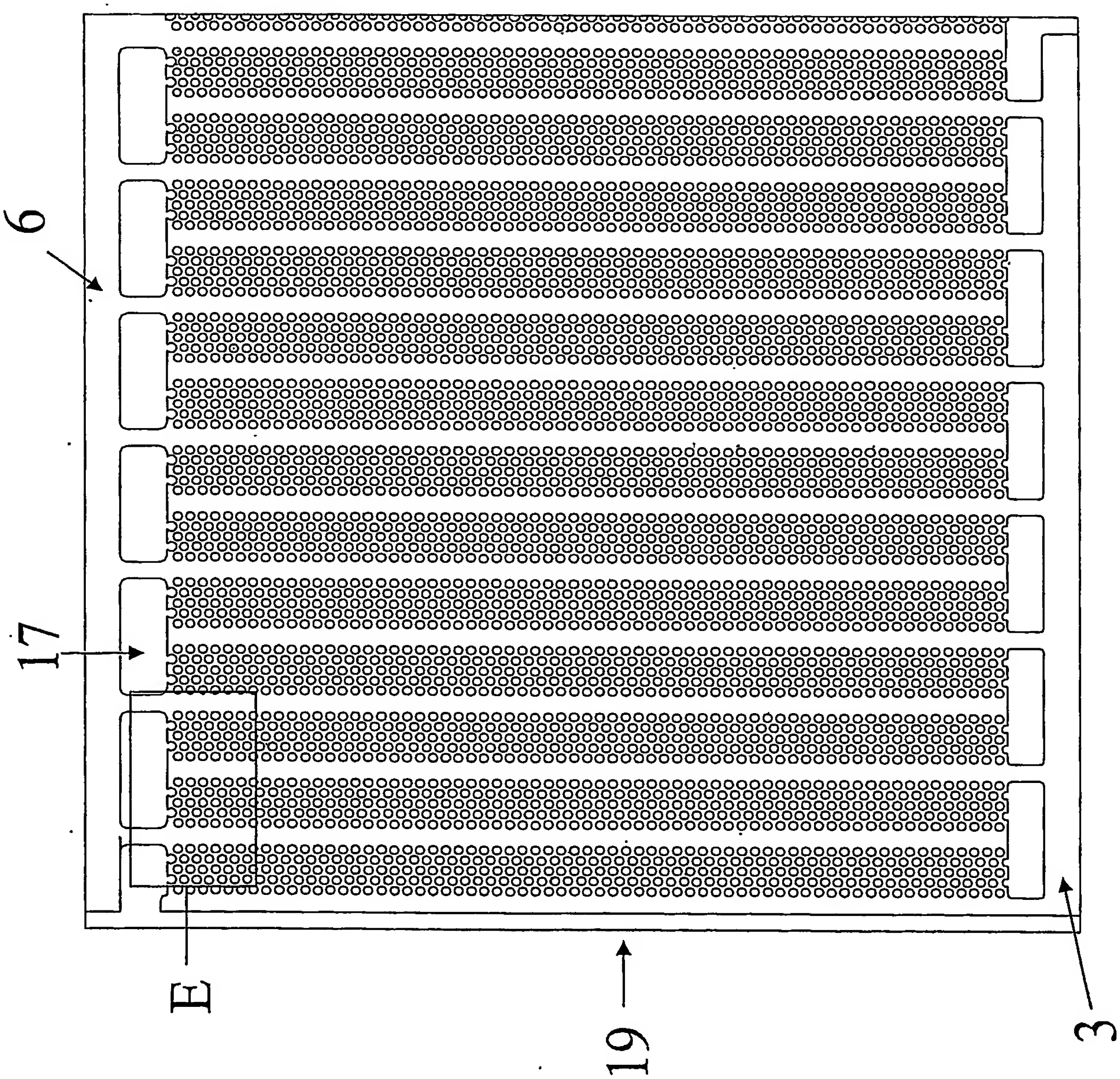


Fig. 3

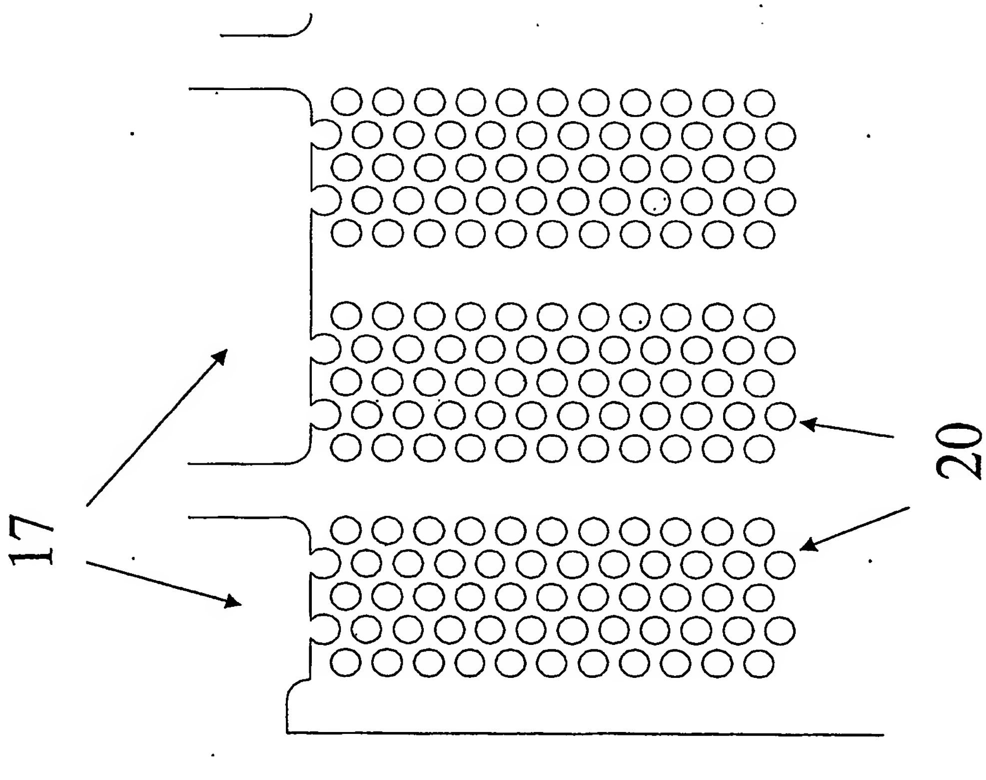


Fig. 4

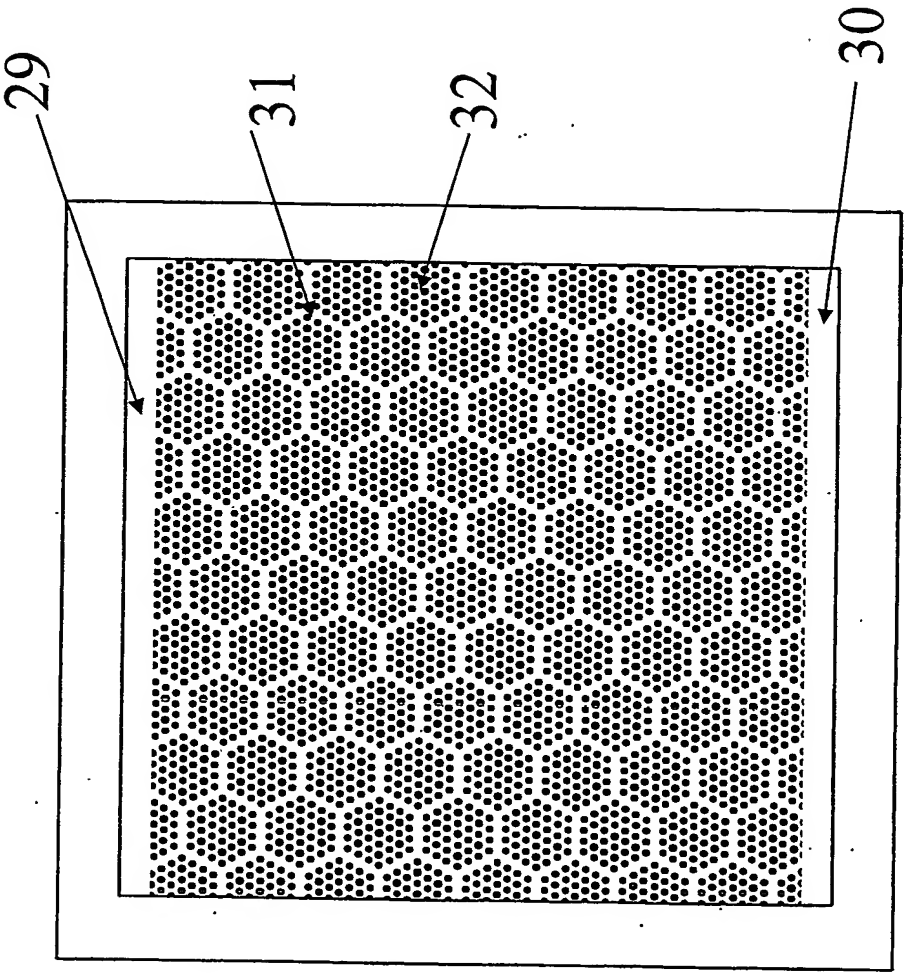


Fig. 5

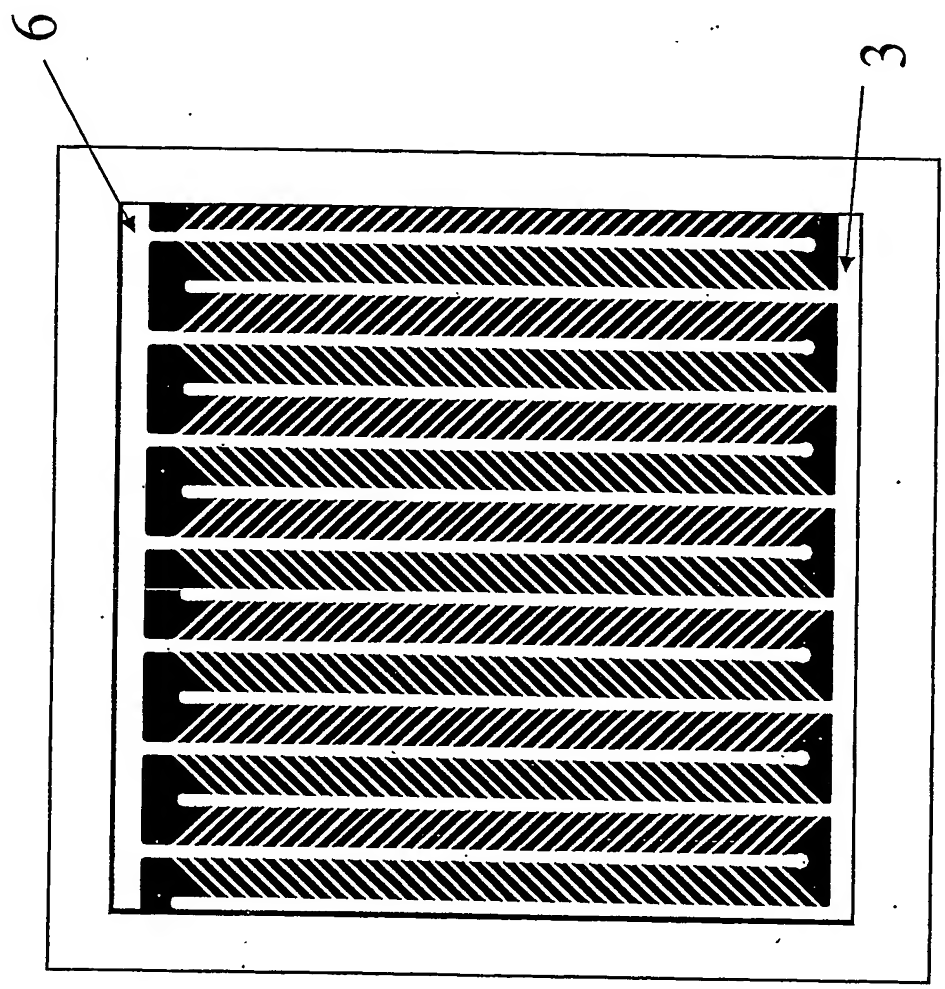


Fig. 6

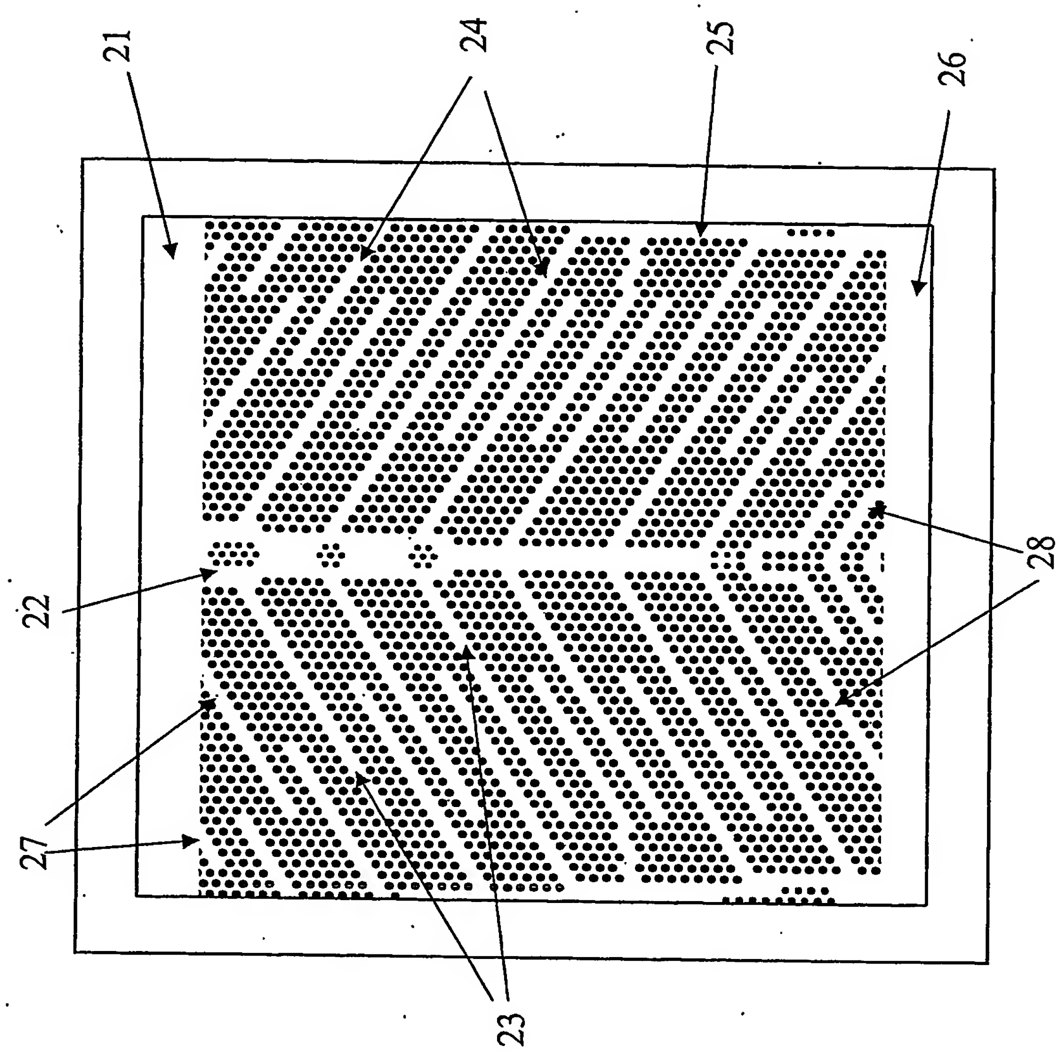


Fig. 7

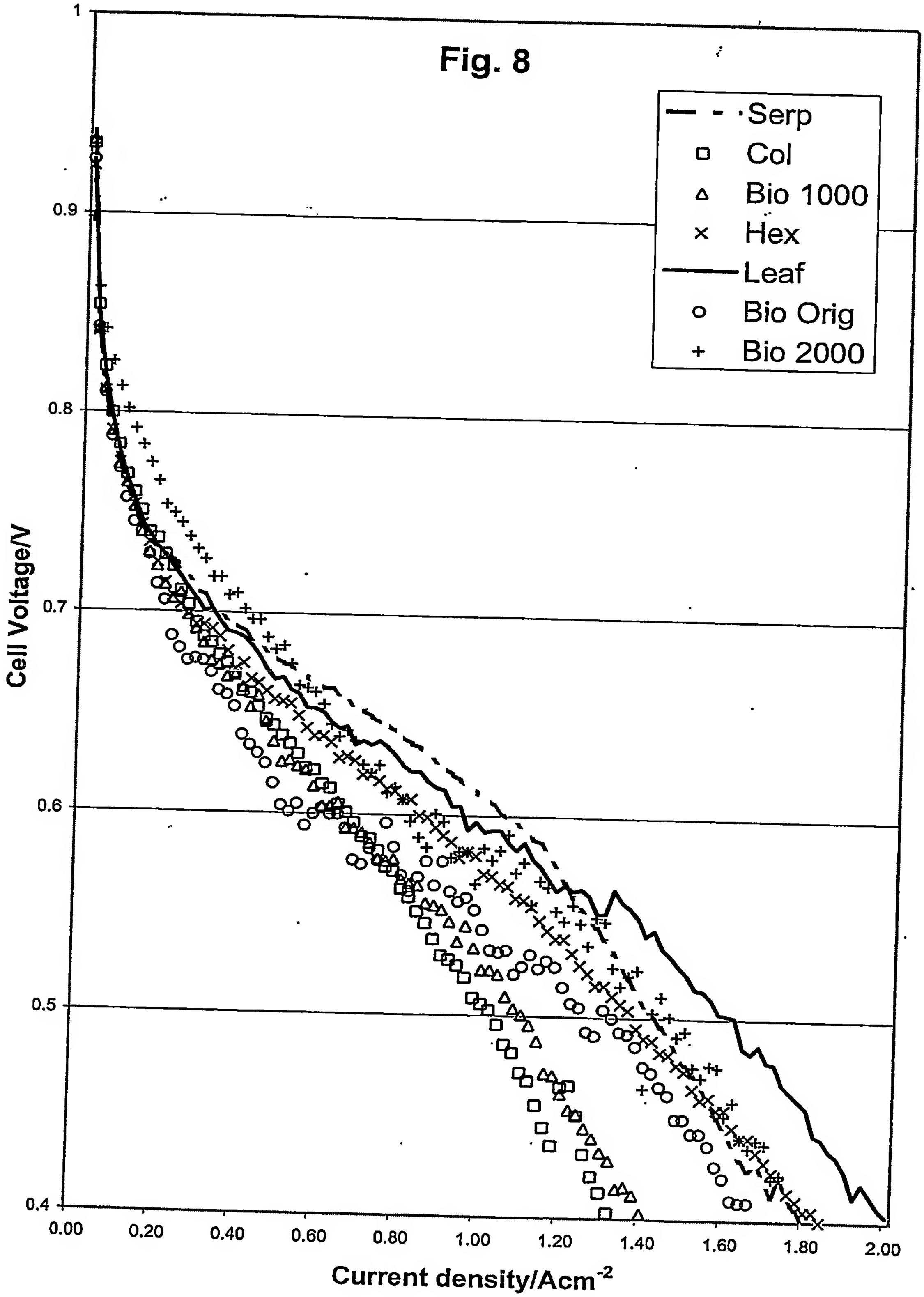


Fig. 8
Serp
Col
Bio 1000
Hex
Leaf
Bio Orig
Bio 2000
Cell Voltage/V
1
0.9
0.8
0.7
0.6
0.5
0.4
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
Current density/Acm-2

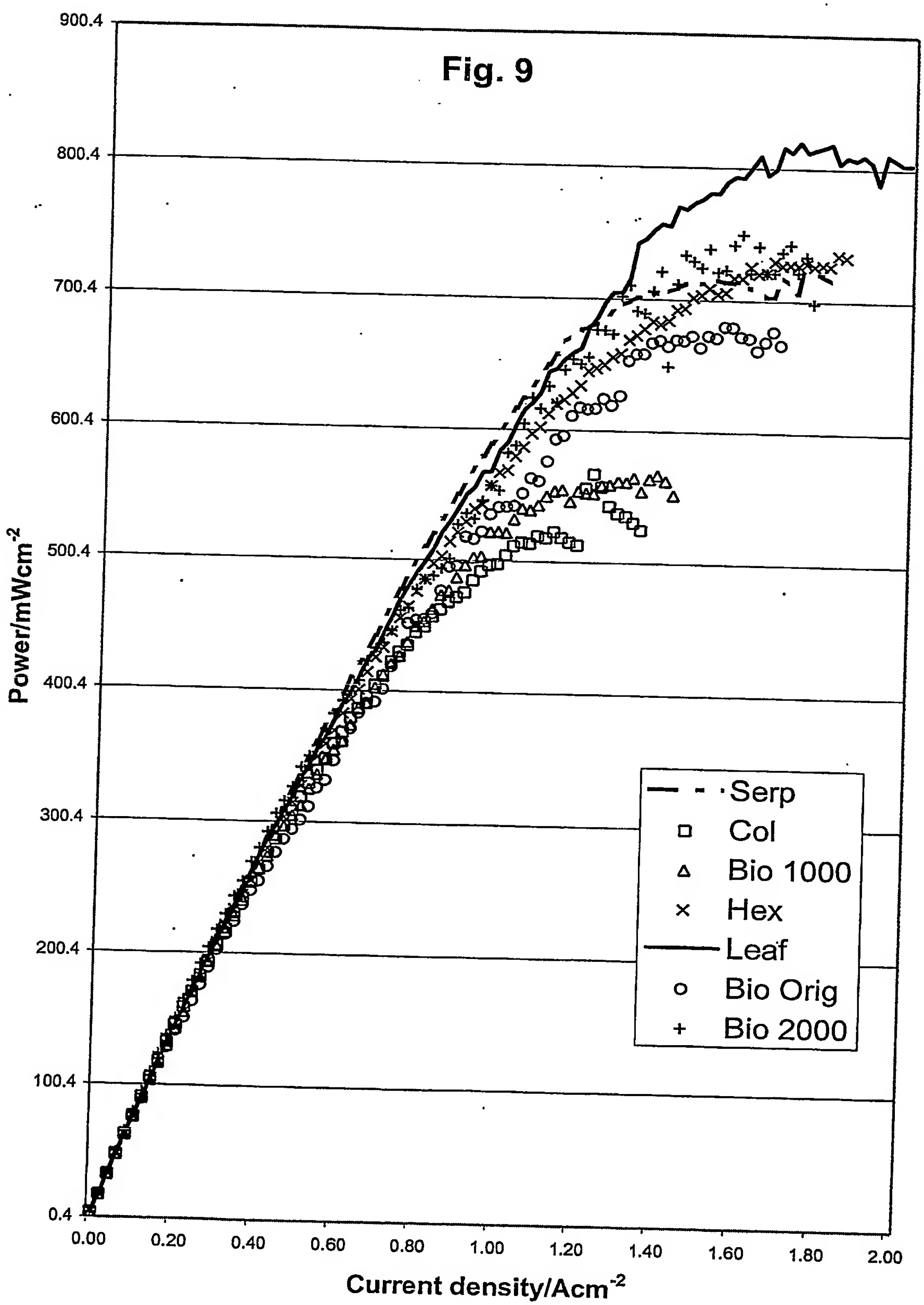
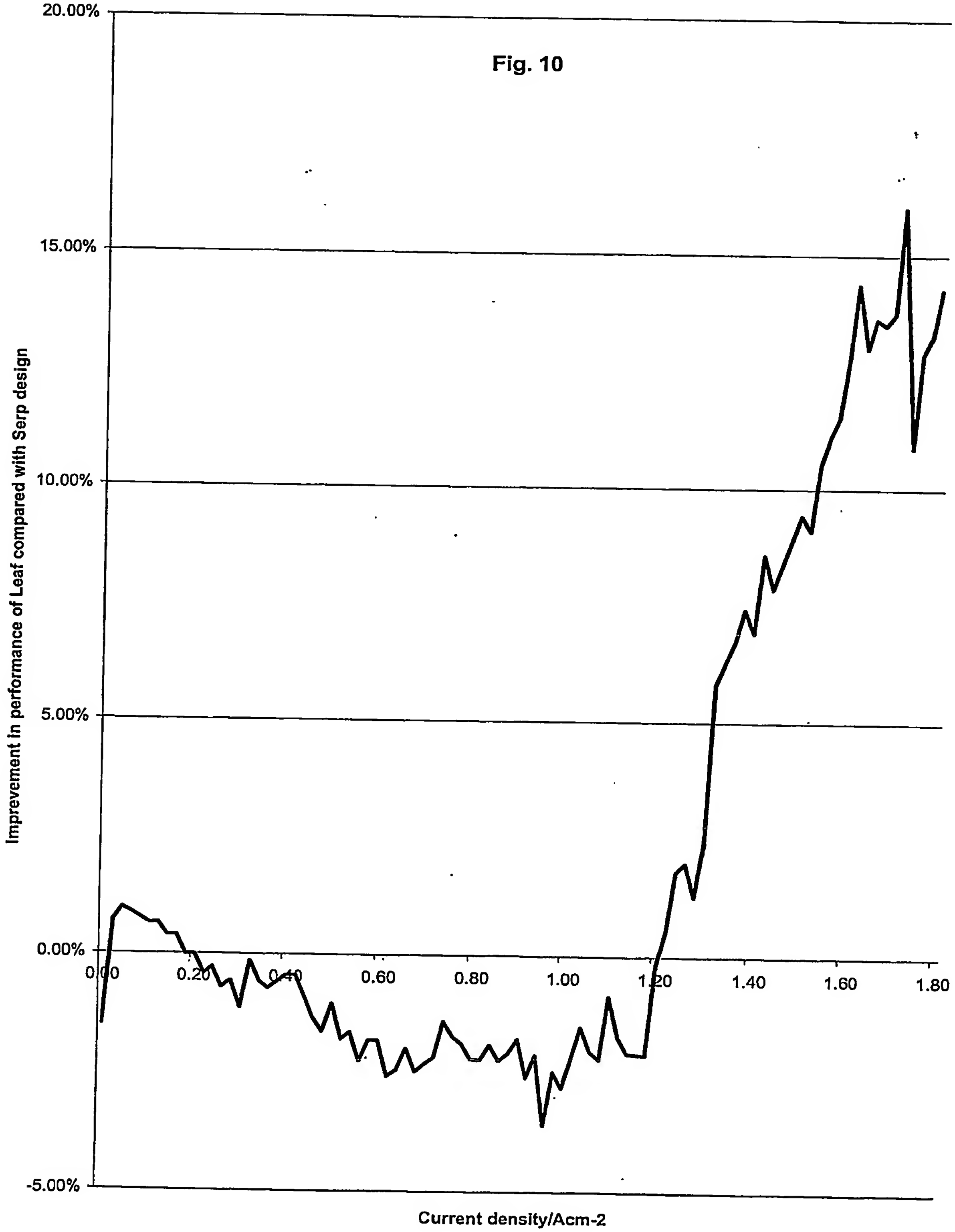


Fig. 9
900.4
800.4
700.4
600.4
500.4
400.4
300.4
200.4
100.4
0.4
Power/mWcm-2
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
Current density/Acm-2
Serp
Col
Bio 1000
Hex
Leaf
Bio Orig
Bio 2000

Fig. 10


20.00%
15.00%
10.00%
5.00%
0.00%
-5.00%
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
Imprevement in performance of Leaf compared with Serp design
Current density/Acm-2

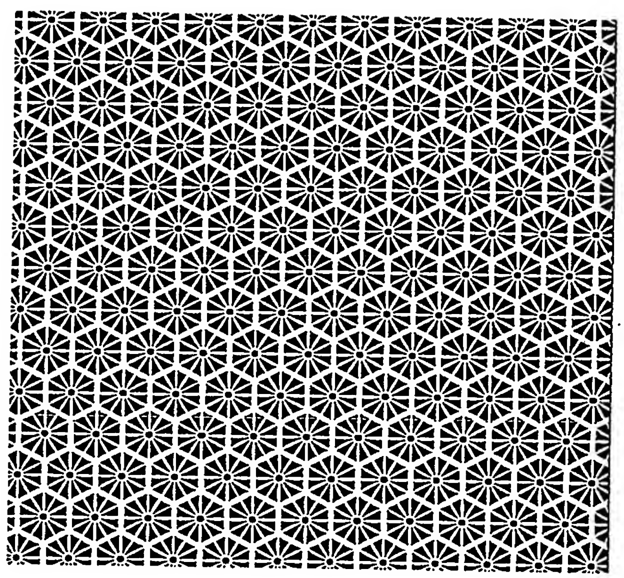


Fig. 11